Velocity based Leg adjustment for walking

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1 Introduction

Swing leg adjustment ,beside bouncing and balancing can be considered as three sub-functions required for legged locomotion. Using template models like spring loaded inverted pendulum (SLIP) [1] for locomotion, swing leg angle adjustment is the only control method to achieve stable gaits [2]. In our previous studies, we presented VBLA (velocity based leg adjustment) as a useful method for explaining humans swing leg control in perturbed hopping [3]. In addition, compared to traditional methods like Raibert approach [4] this approach results in larger range of achievable speeds with less sensitivity to model and control parameter variations [5]. Here, we aim at using VBLA for walking leg swinging and analyze its relation to repulsive function of the leg (bouncing).

2 State of the Art and our Approach

Most of leg adjustment strategies follows the Raibert approach [4] relying on the Center of Mass (CoM) horizontal speed. Recently, various strategies were investigated by Peuker et al. [6] stating that leg placement with respect to the CoM velocity vector $\vec{V}$ and the gravity vector $\vec{G}$ yielded the most robust and stable hopping and running motions. Defining the angle between $\vec{G}$ and $\vec{V}$ by γ and leg orientation α, this method gives the leg orientation by $\alpha = \mu\gamma$, where $0 < \mu \leq 1$. We present VBLA as a modified version of this strategy. As shown in Fig. 1, the leg direction is given by vector $\vec{O}$, a weighted average of $\vec{V}$ and $\vec{G}$,

$$\vec{O} = \mu\vec{V} + (1-\mu)\vec{G} \tag{1}$$

Unlike Peuker's approach which just considers the angle of the velocity vector, in VBLA, both magnitude and angle affect the desired leg direction.

3 Current Results

As pointed in [2], the maximum achievable speed with BSLIP model is about $1.4m/s$. This constraint prevented us to have large speed range as obtained for running. However, this covers humans slow to moderate walking speeds. As can be seen in Fig. 2, considerably large region of stability is obtained with combination of VBLA parameter μ and leg (normalized) stiffness K_N. It means that the control approach is quiet robust against model uncertainties and also perturbations (e.g., variations in motion speed) It is shown that stiffer legs need larger μ meaning steeper leg at touchdown. In other words, we can keep the motion speed with different combinations of swing leg control and leg repulsion behavior. In the left figure, the minimum achievable walking speed shows that for a fixed stiffness, the motion speed can be adjusted by μ. The middle figure shows the tolerable variations of speed for stable walking. It is shown that larger range of walking speeds can be achieved in the middle of the stable region in which a kind of linear relation between μ and K_N can be distinguished. It means that control parameters found in this region are able to produce stable walking with wider speed range. Finally, the fastest obtainable walking speed has more uniformly distribution over μ and K_N. However, for walking with moderate speed similar to humans regular walking speed, the legs should be stiffer and and the attack angle should be larger (smaller μ) than what are needed for slow walking.

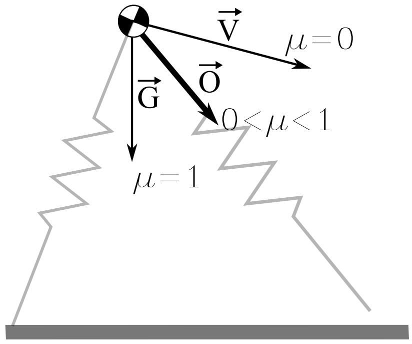

Figure 1: VBLA (velocity based leg adjustment) for BSLIP model

References

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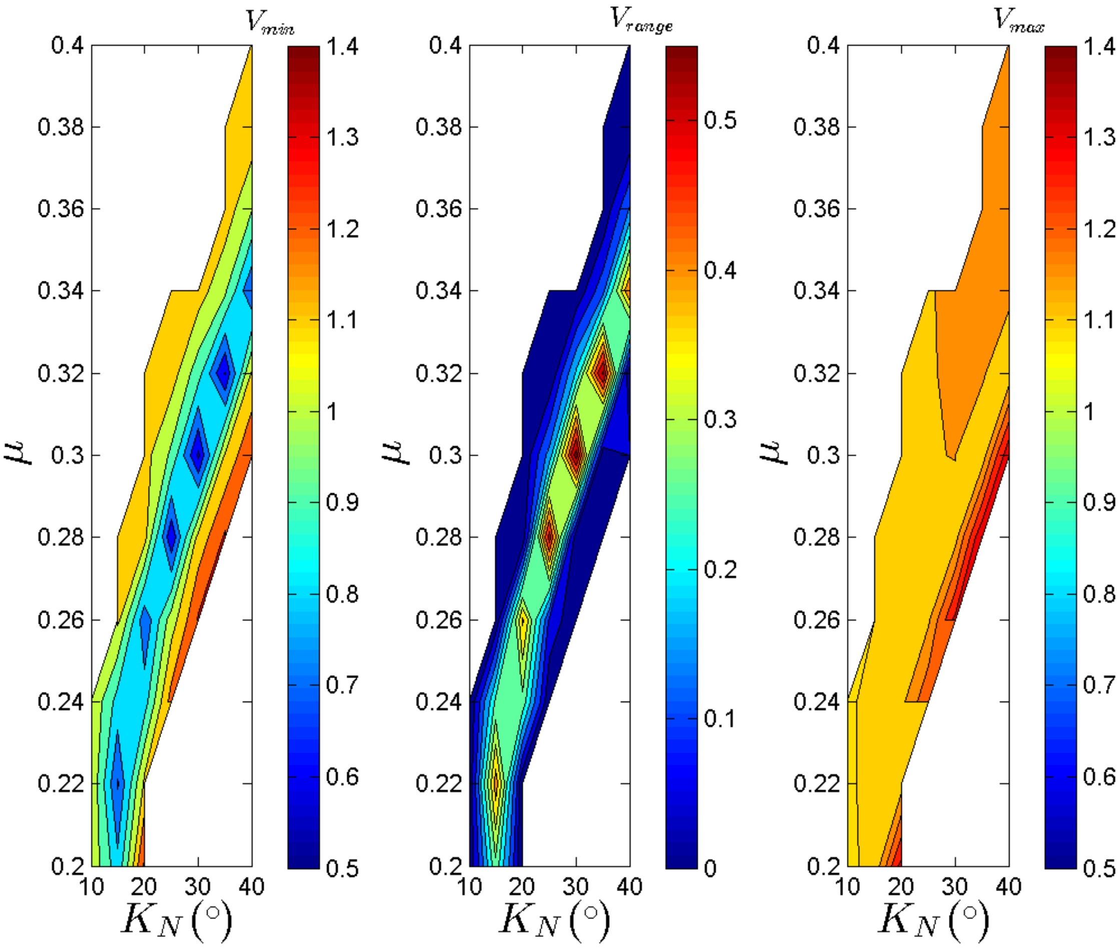

Figure 2: Maximum, range of and minimum speed achieved using BSLIP model with VBLA. The colored area shows the stable region. The relation between normalized stiffness (K_N) and VBLA coefficient μ to have stable walking is shown.